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CONCENTRATED SPRAY MIXTURES AND THEIR APPLICATION BY GROUND AND AERIAL EQUIPMENT AS COMPARED WITH STANDARD SPRAYING AND DUSTING METHODS

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INTRODUCTION

Standard methods for ground and aerial dusting have not been generally effective against forest and shade-tree pests; and standard methods for spraying, while often effective, are limited to relatively small areas, they require large accessible water supplies and expensive high-pressure equipment, and they involve high labor costs.

The search for better methods of control resulted in the development of methods of applying insecticides in the form of highly concentrated spray. The use of concentrated spray mixtures represents an important step in the development of methods for treating areas more quickly, cheaply, and effectively.

These investigations were conducted during the seasons of 1927 to 1938, inclusive, at various points in Massachusetts, New Hampshire, Connecticut, and New Jersey. Standard and special ground equipment, and airplanes and autogiros equipped with devices for disseminating dust and highly concentrated spray, were used.

Although the information reported herein is mostly concerned with concentrated spray, data on dusts and standard spray mixtures are included, primarily for comparative purposes. The advantages and disadvantages of applying insecticides in the form of dust, ordinary spray, and concentrated spray are discussed.

AERIAL AND GROUND EQUIPMENT FOR APPLYING CONCENTRATES

The application of insecticides in concentrated liquid form is a drastic departure from standard spray methods. Distribution is best accomplished with equipment designed to produce a fine mist by applying air pressure to the liquid as it is released from the spraying device. Application requires very little pressure, time, or labor. The ingredients may be mixed in the spraying apparatus or carried to the field already mixed.

Aerial Equipment

Aerial equipment for atomizing spray has consisted mostly of air-driven rotary or centrifugal devices. These devices have not been entirely satisfactory since they tend to throw part of the mixtures up on the aircraft, and they do not always cause fine atomization. Ground tests indicate that other types of apparatus, which utilize the principle of pressure or air atomization and which will be lighter, simpler, and more efficient than centrifugal devices can be made.[1]

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[1]Detailed descriptions of aerial apparatus used in the tests are contained in two unpublished manuscripts that have been offered for publication, and in the following published paper: Potts, S. F. Spraying woodlands with an autogiro for control of the gypsy moth. Jour. Econ. Ent. 32: 381-387, illus. 1939.

Ground Equipment

Certain types of ready-made equipment now available on the market can be assembled or modified for use in applying concentrates, although it is believed that equipment designed especially for this purpose would be much more efficient. The following types of equipment were tested: A hand atomizer, a knapsack sprayer, a wheelbarrow sprayer, a power orchard sprayer, and a portable, power, paint spray assembly. Two new types of nozzles were used: One (fig. 1) for applying concentrates with ordinary ground spraying equipment, and the other, an ordinary paint spray gun (fig. 5), for use with paint spray outfits (fig. 4).

The ordinary hand atomizer, of $\frac{1}{4}$ to 2 pints' capacity and costing not over 25 cents, offers inexpensive equipment to any home owner for applying concentrates quickly to small areas of low-growing plants, trees, and shrubs (table 1). Although it exerts less than 10 pounds of air pressure, this simple apparatus deposited 1,000 droplets of lead arsenate spray per square inch of leaf surface, averaging 0.2 microgram of lead arsenate per droplet, when lead arsenate was used at the rate of 15 pounds per acre. To compare the rate of coverage of a concentrate applied by a quart-sized hand atomizer with that of a standard spray mixture applied by a $2\frac{1}{2}$-gallon knapsack sprayer, two 0.07-acre plots of low deciduous growth were treated with the two forms of spray, 1 pound of lead arsenate being used for each plot. One quart of concentrate and 3/4 hour were required to cover one of the plots by means of the atomizer, while 33 gallons of standard spray mixture and 5 hours were required when application was made to the other plot of the same size by a knapsack sprayer. When the aperture (1/32 inch, or 0.8 millimeter) of the knapsack sprayer nozzle was fully open, the standard spray mixture was delivered at the rate of only 12 gallons per hour, and it was necessary to refill the tank with spray 16 times, and to pump air into the tank 48 times, while delivering the 33 gallons of mixture. On the other hand, it was necessary to fill the atomizer only once.

Knapsack sprayers cover areas rapidly with concentrates, but the atomization is not sufficiently fine (fig. 2) for effective control of sucking insects, although effective control of most leaf-eating insects can be obtained. The disc type of nozzle which accompanies most knapsack sprayers produces a hollow cone type of spray. A type of nozzle (fig. 1) which produced a solid cone type of spray was made, and its use resulted in a more satisfactory application of the spray to specific parts of the plants being treated. It reduced the spray output by half and considerably improved the atomization and distribution.

With a wheelbarrow sprayer from 2/3 to $1\frac{1}{2}$ acres of low growth were treated per day with ordinary spray mixtures, whereas 4 acres were treated per day with concentrated spray.

High-powered orchard equipment was next tested by applying concentrates and conventional sprays through standard vermorel and disc nozzles at 300 pounds' nozzle pressure to dense stands of 2,000 to 3,000 Japanese black pine and red pine trees per acre. The trees were in large nurseries and

were 5 to 9 feet tall. The small quantity of water used in the concentrate reduced water hauling and made it possible for 4 laborers to operate the sprayer, whereas 6 laborers were required to operate this outfit when applying the conventional spray. Coverage with concentrates was at the rate of 6 acres per day, as compared with 1 to 2 acres per day for the conventional spray. Eight gallons of concentrate or 800 gallons of ordinary spray were applied per acre (table 1). The atomization and distribution of the concentrate were satisfactory for controlling medium-sized to large leaf-eating insects when the above-mentioned nozzles were used, but the spray was too coarse for controlling sucking insects, because only 50 droplets were deposited per square inch of foliage. Also, it was necessary for the nozzle man to move rapidly in order to avoid overspraying.

A power paint-sprayer assembly that was satisfactory for applying concentrates is shown in figures 4 and 6. The assembly consists of a small gasoline engine, an air compressor, a small tank to remove pressure pulsations and hold the insecticide mixture, two lines of 1/4-inch hose, one line of which carries air while the other carries liquid, and a paint spray-gun nozzle mounted on an extension rod. A wire extends along the extension rod to the trigger of the gun for use in releasing the spray. The whole equipment is set on a metal base and mounted on a wheelbarrow chassis or set in a truck (fig. 4). This device finely atomizes oils and other fluid concentrates by applying compressed air to a stream of spray outside the nozzle. Atomization by this arrangement required 50 pounds' nozzle pressure, and nozzle apertures for air with a combined surface area from 2 to 4 times as great as that of the apertures for the liquid. The aperture for liquid ranged from 1 to 2 millimeters (1/25 to 1/12 inch) in diameter. Low deciduous growth (figs. 3 and 6) was covered at the rate of 6 acres per day and with an average of 1,000 to 1,200 droplets of concentrate per square inch of leaf surface.

At present, equipment can be assembled for applying concentrates to trees up to 15 to 20 feet in height. It will be necessary to develop new types of machinery and accessories for trees over 20 feet in height, in order to apply from 3 to 10 gallons of concentrate per acre, instead of the machinery which now applies 500 to 1,000 gallons of standard mixture per acre. New equipment should be designed to release atomized spray above the tree tops, or to drive it into the trees from below with a blower, as for dusts. Such an outfit should be light and inexpensive and should require very little pressure for atomization. Any hose attachment should be small and light. The outfit should require very little labor for operation and should cover areas rapidly with a minimum of cost.

Physical Properties of Mixtures in Relation to Equipment

The physical nature of the mixtures greatly influences the kind of equipment needed for their application. If mixtures are very viscous or if they contain corase, granular materials they will not flow freely through ordinary mist nozzles. Therefore, in order to prevent clogging it is often desirable either to strain the mixture or to atomize it outside the spraying

Table 1.--Comparison of ground equipment used in these tests in applying ordinary and concentrated sprays to low growth

Kind of equipment	Nature of spray concentration	Pounds of pressure	Acres sprayed per 8-hour day	Number of men to operate	Approximate cost of equipment	Labor cost per acre at $3.00 per man-day	Remarks[1]
Quart hand atomizer	Ordinary spray	Very little pressure	0.03	1	$0.25	$100.00	Concentration of 3 pounds of lead arsenate per 100 gallons of water.
	Concentrated spray	Do.	.70	1	.25	4.30	Concentration of 1 pound of lead arsenate per 1.5 pounds of water, plus wetting agent.
Knapsack sprayer	Ordinary spray	50	1/8 to 1/4	1	18.00	12.00 to 24.00	
	Concentrated spra	50	2½	1	8.00 to 18.00	1.20	Atomization not so good as for hand atomizer or portable atomizer, figure 4.
Wheelbarrow sprayer (hand operated)	Ordinary spray	150	2/3 to 1½	2	35.00	4.00 to 9.00	
	Concentrated spray	150	4	2	35.00	1.50	Atomization not so good as for hand atomizer or portable atomizer, figure 4.
Power orchard sprayer	Ordinary spray	300	1 to 2	6	500.00	9.00 to 18.00	The growth was much more dense than the growth treated with the other equipment.
	Concentrated spray	300	6	4	500.00	2.00	Atomization not so good as for hand atomizer or portable atomizer, figure 4.
Portable pressure atomizer (figure 4)	Concentrated spray	50	6	2	100.00	1.00	Atomization good, but could be improved.

[1] When insecticides are applied as concentrates instead of as ordinary spray or dust, less insecticide is required. This makes possible a reduction in the cost of insecticidal material per acre.

device by means of a power-driven blower, or by air pressure as shown in figure 6. Most of the mixtures applied flowed nearly as freely through small spray hose, attachments, nozzles, and viscosimeters (fig. 7) as ordinary spray concentrations. Such a mixture is called a fluid mixture.

In some aircraft the available space for an insecticide container is very limited. This problem has been partially solved by applying the insecticide in the form of a liquid instead of as a dust, since a given weight of material occupies less space as a liquid than as a dust. Dusts usually weigh from 15 to 30 pounds per cubic foot, while liquids weigh from 56 pounds per cubic foot, in the case of light oils, to 113 pounds per cubic foot, in the case of the heaviest mixtures. A 5-cubic-foot (37-gallon) tank holds 450 pounds of lead arsenate concentrate, of which 210 pounds is lead arsenate, whereas a dust hopper of the same volume holds only 100 pounds of the same brand of uncoated dust.

Degree of Atomization Desired

Finely atomized droplets cause less foliage injury and are more effective as a stomach poison against small insects or as a contact poison against sucking insects than coarsely atomized spray. Finely atomized spray drifts more than coarse spray, but not nearly so much as dusts. A small droplet is equal in volume and weight to a number of dust particles. For a given bulk the liquids were from 2 to 7 times as heavy as dusts. A deposit of 1,200 oil droplets per square inch was sufficient to give complete coverage, since the droplets coalesced and the oil spread over the entire surface. When applied as a stomach poison for most leaf-eating insects, 300 droplets per square inch was found to be sufficient. For some of the snout beetles and extremely small chewing insects a deposit of as many as 1,000 droplets per square inch was required, whereas for small sucking insects a deposit of at least 1,200 droplets per square inch was essential. Microscopic counts of droplets of finely atomized sprays on leaves showed that an average deposit of 5,000 to 7,500 droplets per square inch is attainable. Thinning and wetting agents considerably increased the atomization of all oils, the increase in number of droplets deposited per given area being from 5- to 10-fold in the case of heavy oils.

LABORATORY AND FIELD STUDIES OF CONCENTRATED SPRAY MIXTURES

In the laboratory special attention was given to methods of combining ingredients necessary to make the most fluid, concentrated, stable, economical, and effective mixture.[2] The ingredients were mixed in lots of $\frac{1}{4}$ to 1 gallon by means of an electric mixer.

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[2]Other methods of preparing concentrated spray mixtures are discussed in two unpublished manuscripts that have been offered for publication, and in the following published paper: Potts, S. F. Concentrated mixtures for aerial spraying. Jour. Econ. Ent. 32: (4): 576-580, 1939.

General Procedure Followed in Preparing Mixtures

Except in the case of undiluted oils, the mixtures contained an insecticide added, in the form of powder, extract, or oil, to an oil or water carrier, plus one or more of the following: (1) A wetting or spreading agent, (2) an adhesive such as casein or an adhesive oil, or (3) certain materials such as glycerine or diethylene glycol to absorb atmospheric moisture and resist too rapid drying of the mixtures. Mixtures containing water as a carrier were quick-breaking emulsions of the oil-in-water type,[3] to which water can be added to make any dilution desired.

When an insecticide and water were mixed with oil and such wetting agents as sodium lauryl sulfate or aresket, the wetting agent was dissolved in a volume of water equal to the volume of oil to be used. This solution was poured slowly into the oil while it was stirred or agitated until a good emulsion resulted. The insecticide was then added and the mixture agitated.

When the insecticide and water were to be added to oil and oleic acid plus triethanolamine $N(C_2H_4OH)_3$, the last three ingredients were mixed together first. Then an equal volume or weight of water was added slowly, and stirred until a creamy emulsion resulted. Then the remainder of the water was stirred in and the insecticide added.

When either casein or casein glue (casco) was used as a sticker, triethanolamine was dissolved in the total amount of water, the casein product was added, and the mixture was stirred until a good emulsion resulted. The insecticide was then added. In water, casein glue dissolved slowly, but casein (slightly acid) was insoluble. Therefore triethanolamine (pH 10 to 11 in water) was used to dissolve casein in water, at the rate of 0.05 to 0.15 part of triethanolamine per 1 part (by weight) of casein.

When casein glue and triethanolamine were used as a spreader, the casein glue and organic amine were dissolved in 3 parts of water. Oil was added, and the mixture stirred until a good emulsion resulted. The remaining water was then added and the insecticide stirred in.

When sulfonated castor (turkey red) oil was used as a wetting agent or emulsifier, the turkey red oil and other oil to be added were mixed and stirred in an equal volume of water. Stirring was continued until a good emulsion resulted. The remaining water was added and the insecticide stirred in. More turkey red oil was required than alkylphenylbenzenesulfonic acid, but it was cheaper and less likely to decompose certain insecticides.

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[3]A different mixing method sometimes used in the field for powdered insecticides consisted of adding a wetting agent to the water, and then adding the insecticide and oil, in the order given, while the mixture was being agitated.

The general procedure outlined above was followed in preparing the mixtures described below. These preparations represented the most concentrated fluid mixtures obtained with the materials and methods used.

Description of the Mixtures

Lead arsenate.--All lead arsenate mixtures contained some water, and usually an adhesive oil and a wetting agent (fig. 7) were added. All lead arsenate used was the ordinary acid form. Without a wetting agent, 2 to 4 pounds of water were required per pound of lead arsenate. With all 14 brands tested, the use of suitable wetting agents made possible the preparation of fluid mixtures containing 1.25 pounds of water per pound of lead arsenate. A common mixture contained 1.25 pounds of water, 0.02 to 0.04 pound of wetting agent (as sodium lauryl sulfate), and 0.2 pound of corn oil or soybean oil per pound of lead arsenate. A gallon of this mixture weighed 11.33 pounds and contained 4.25 pounds of lead arsenate. Three and one-half gallons of this mixture were required for applying 15 pounds of lead arsenate per acre. In using colloidal lead arsenate paste, 3 pounds of water were required per pound of insecticide to produce a fluid mixture.

A laboratory-prepared lead arsenate, which was not so fine as commercial brands, required only 0.88 pound of water per pound of arsenical in making a fluid mixture. The final mixture, including wetting agent and adhesive, contained 51 percent of lead arsenate by weight. Particle size and shape had an important bearing on the quantity of water necessary to make a fluid mixture.

Calcium arsenate.--The most concentrated fluid mixtures prepared contained 0.03 pound of triethanolamine and 1.5 pounds of water per pound of calcium arsenate. All calcium arsenate used was the ordinary commercial form.

Synthetic cryolite.--The most concentrated fluid mixtures prepared contained 1.2 pounds of water, 0.2 pound of an adhesive oil, and 0.02 pound of triethanolamine per pound of pure cryolite. Some brands of cryolite containing a dye and 17 to 25 percent inert ingredients, required 2.5 pounds of water per pound of powder to make a fluid mixture.

Barium fluosilicate.--The most concentrated fluid suspension containing an adhesive consisted of 0.8 pound of water, 0.2 pound of oil, and 0.02 pound of alkylphenylbenzenesulfonic acid (aresket) per pound of barium fluosilicate.

Sulfur.--One pound of sulfur or of sulfur-bentonite clay was used in mixtures containing 1.25 pounds of water, and 0.2 pound of soluble casein glue, high-fat-content soybean flour, or paraffin oil. The addition of triethanolamine or aresket increased the fluidity of the mixtures.

Nicotine compounds.--Highly concentrated mixtures were prepared containing nicotine sulfate or free nicotine, either in oil or in oil and water. A mixture frequently used contained 6 pints of water and 2 pints of oil per

pint of nicotine solution; it was applied at the rate of 2 to 4 gallons per acre.[4] In nicotine sulfate mixtures a dissolved nonalkaline emulsifying agent should be added to the water in quantities sufficient to make a good suspension. No emulsifier or spreader is needed for free nicotine mixtures. When nicotine was used as a stomach poison, semidrying oils were superior to drying and nondrying oils as carriers. When only contact action was desired, a nondrying plant or mineral oil was superior.

The most concentrated fluid mixture of dual-fixed nicotine (containing 7.5 percent of nicotine, of which part is soluble and part is insoluble) consisted of 1 pound of dual-fixed nicotine, 2 pounds of water, 0.4 pound of oil, and 0.02 pound of aresket, making a nicotine content of 2.2 percent in the final mixture.

The most concentrated fluid quebracho-fixed nicotine mixture applied contained 1 pound of quebracho-fixed nicotine, 0.67 pound of water, and 0.3 pound of oil. It is interesting to note that oil slightly increases the fluidity of this mixture, since the opposite result was expected. It is better to add the fixed nicotine to the water than to reverse the procedure. The oil is added last.

Derris.--Derris and cube are easily wetted with aresket. The most concentrated mixture prepared contained 5 pounds of water, 0.04 pound of this wetting agent, and 0.3 pound of semidrying oil per pound of derris or cube.

Solidified derris extract.--The most concentrated mixture prepared contained 1 pound of derris extract (containing 25 percent of rotenone), 2 pounds of acetone (or preferably some noninflammable solvent when applied by aircraft), and 1 pound of oil. This mixture is 577 times as concentrated in rotenone content as a mixture of 3 pounds of derris (containing 4 percent of rotenone) per 100 gallons (834 pounds) water. The contact effect of derris and derris extract was improved by extracting in certain plant oils, such as cottonseed oil, cashew nut oil, or peanut oil, and then diluting with white mineral oil of 50 seconds Saybolt viscosity.

Phenothiazine.--Before being added to the mixture, the phenothiazine should be passed through a 12- to 20-mesh screen to break up the lumps. The most concentrated mixture prepared contained 1.2 pounds of water and 0.04 pound of aresket per pound of phenothiazine. This mixture possessed practically no adhesiveness, but the addition of casein glue and soybean flour greatly increased adhesion without causing plant injury. The addition of oil caused foliage injury.

Copper compounds.--Bordeaux mixture concentrate contained from 6 to 8 pounds of water per pound of copper sulfate in the mixture, when water was

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[4]The question is often asked as to whether talc or dye material should be added to certain concentrates to render the deposit more perceptible on the foliage. Tests made thus far indicate that this is not necessary.

used as the carrier. When oil was used as the carrier for dehydrated copper sulfate-hydrated lime concentrates, from 5 to 8 pounds of volatile (45 seconds Saybolt viscosity) mineral oil containing 0.05 to 0.2 pound of suitable oil-soluble wetting agent (such as Vatsol O.T. or Grasselli IN2503) plus 0.3 pound of drying oil was used per pound of copper sulfate.

When lime was omitted, 3 pounds of water was used per pound of copper compound in concentrates containing copper in the form of basic copper sulfate, copper ammonium silicate, copper oxide, or copper hydroxide. Since all mixtures prepared at this concentration were very fluid, it is likely that the proportion of water in the mixtures can be considerably reduced. As these unlimed copper compounds were applied late in the season it was not determined whether they are safe on tender foliage.

Oil concentrates.--Unemulsified oils as well as oil emulsions and miscible oils can be applied as contact insecticides. Thick oils do not atomize or spread so well as thin oils. Therefore, when the viscosity was greater than 100 seconds Saybolt, from 10 to 50 percent (by volume) of a volatile "thinner" or solvent, such as acetone, refined kerosene, or petroleum ether, was often added to the oil. The "thinner" evaporated quickly and therefore caused no plant injury In some cases from 20 to 40 percent (by volume) of water was added to miscible oils and oil emulsions to increase the rate of flow and atomization.

Storage Tests

Field tests of numerous concentrated spray mixtures that had been held in storage for 3 years show that mixtures containing arsenicals and many other insecticides can be stored safely and sold on the market ready for use without further mixing or dilution. Some organic insecticides, as derris, could not be stored for long periods of time owing to the adverse effect of bacteria and fungi. To prevent the development of bacteria and fungi, small quantities of coal-tar dyes, sodium benzoate, or copper sulfate were added to these mixtures. Most of these preservatives stopped the action of the organisms, but the best kind and quantity of preservative to use is still not definitely known. Light, air, and high temperature tend to decompose certain organic materials, as derris. Containers should therefore exclude light, and should be airtight and filled to the top. They should then be stored in a cool place.

Wetting and Spreading Agents[5]

Wetting or spreading agents and oils were among the most common and important materials used in concentrated spray mixtures and were given careful consideration with respect to their effects on the plant, insecticide, and cost of treatment.

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[5]Some brands of insecticides were colored with an organic pigment (beta naphthol and tobias acid, derived from coal tar) which reduced the efficiency of sodium lauryl sulfate but did not affect the use of such wetting agents as turkey red oil and triethanolamine oleate.

In order to learn the phytotoxicity of wetting or spreading agents alone, 5-percent concentrations of areskap, ultrawet, aresket, aresklene, triethanolamine, sodium lauryl sulfate, or triethanolamine oleate were applied to wild black cherry. Although rain on the third day after treatment removed all the spreader, serious injury was caused by them in the descending order as listed above. At this concentration, casein, casein glue, soybean flour, and sulfonated castor oil caused no injury. At concentrations commonly used in applying standard sprays, oil emulsions, or miscible oils, a number of the 27 wetting and emulsifying agents investigated contained sufficient alkali or acids to cause at least slight injury to tender plants.

Insecticidal decomposition, solubility, and foliage injury were reduced to a minimum by using concentrated spray mixtures, since only 4 to 14 percent as much wetting agent and 0.4 to 2 percent as much water was applied per acre as is used in applying ordinary spray concentrations. Often the wetting agent can be omitted entirely, as in the application of undiluted oils and free nicotine.

Leaf analyses showed that when most spreaders were used in standard spray mixtures the initial deposit was only about half as great as when they were omitted. Furthermore, they increased the loss of deposit by rain from 25 to 40 percent. In concentrated spray applications there was no reduction of initial deposit by run-off and drippage, and wetting agents caused no great loss of deposit by rain.

Wet foliage increased the spreading of concentrated spray deposits and made possible the use of less spreader than when the foliage was dry. Also, when added to concentrated spray mixtures, compounds which absorb moisture from the air increased the spreading of the deposit.

The cost of wetting agents is reduced to a minimum when applied in concentrated spray. For example, the application of 18 pounds of insecticide in a conventional spray, consisting of 3 pounds of insecticide per 100 gallons of water, required 6 pounds or $1.50 worth of wetting agent, but when applied as a concentrate only 18 cents worth of wetting agent was required.

Suitable wetting agents should reduce the amount of water or carrier required to make a fluid concentrate, improve the physical properties and spreading of the mixture, and facilitate quicker mixing. They should not be expensive, cause excess foaming, reduce adherence of deposits, or cause foliage injury.

Oils In Relation to Concentrated Spray Mixtures and Plant Injury

Oils serve one or more purposes in concentrated spray mixtures, depending on the kind of oil and the end sought. They may serve as a carrier, adhesive, spreading and penetrating agent, or solvent for oil-soluble insecticides, or to protect tender foliage by coating the insecticidal particles. They may prevent too rapid drying of the insecticidal mixture, reduce volatilization of certain insecticides, and retard decomposition of the insecticide by weathering. Oil can be used as a carrier in place of water for free nicotine, pyrethrum extract, rotenone, and derris extract. However, when most powdered insecticides, oils, oil emulsions, and miscible oils are being applied, an oil should not be used as the carrier, owing to the large volume of oil carrier required per given weight of insecticide, its cost, and the danger to tender plants in the case of a nonvolatile, nondrying oil.

Unemulsified drying and semidrying oils, as linseed, fish, corn, soybean, and cottonseed oil, were good adhesives and safe on tender foliage. They arrested the decomposition or volatilization of such organic insecticides as free nicotine, derris, and derris extract. Drying oils form a protective dry film or coating around the insecticide particles. This film apparently prevents dew and rain water from attacking or dissolving the insecticide and at the same time protects the plant against direct contact with the insecticide. The drying oil remains with the insecticide and spreads less than a nondrying oil. Nondrying oils and volatile oils are poor adhesives, and their use often makes frequent retreatments necessary.

When finely atomized concentrates containing water and drying oil were applied at temperatures of 73° F. or higher, accompanied by relative humidities of 50 percent or less, too rapid drying of the oil often occurred, causing the formation of hard, dry pellets which rolled off or blew off the foliage. This condition was corrected either by substituting a semidrying oil (such as corn oil, soybean oil, or cottonseed oil) for the drying oil, or by mixing 1 part of nondrying oil with 2 to 5 parts of drying oil. Peanut oil, motor oil, or a paraffin oil costing 15 cents per gallon have been added to the drying oil for this purpose. Large proportions of either nondrying oils or emulsifying agents tend to reduce the adhesive value of the drying oil

In cases where it may be undesirable for the insecticide to adhere firmly to the plant for long periods of time, there are several alternatives, such as (1) omitting or greatly reducing the quantity of adhesive oil in the mixture, and (2) substituting for the adhesive oil a volatile or nondrying oil, or glycerine, diethylene glycol, or Yumidol (a nonvolatile, hexahydric alcohol), which absorb atmospheric moisture and cause the insecticide to be picked up on the feet and bodies of insects crawling over sprayed surfaces.

DISCUSSION OF FIELD INVESTIGATIONS OF INSECTICIDAL RESIDUES

Although numerous compounds appear to be very toxic to insects in the laboratory, only a small percentage of these are at present of practical value in the field. This may be due to a number of reasons, such as failure to obtain a sufficient insecticidal deposit on plant parts or insects; poor adherence; decomposition after exposure on the leaves in moisture which usually contains dissolved carbon dioxide and plant acid from the leaves; weathering; and injury to foliage.

In the field special attention was given to the deposit, atomization, spreading, drift, distribution, adherence, and phytotoxicity. Concentrates (table 3), prepared in the manner just described, were applied to approximately 300[6] plots ranging in size from 0.02 to 0.07 acre (900 to 3,000 square feet), of uniformly stocked deciduous sprout growth 4 to 8 feet tall. For comparative purposes the same quantity of insecticidal agent was applied per plot when concentrates were used as when conventional sprays were used. Ordinary spray concentrations (table 2) were applied with a knapsack sprayer. Dust mixtures were applied with a bellows-type knapsack duster to plots of 0.1 to 0.4 acre.

The text which follows is a discussion of the degree of foliage injury, the degree of adherence, and the quantitative measurement of deposits resulting from the use of various insecticides and insecticidal combinations, applied from the ground or from the air in the form of dust, ordinary spray concentration, or concentrated spray.

Foliage Injury Tests

Tables 2 and 3 show the injury caused by certain insecticidal preparations to foliage of the most susceptible woodland tree (wild black cherry). Table 2 is concerned with ordinary spray concentrations, while table 3 is concerned with concentrated spray mixtures. Both tables give the spray ingredients used, the degree of concentration, adherence, solubility, and the degree of plant injury which followed.

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[6]Lack of space does not permit data on hundreds of the concentrated spray, ordinary spray, and dust mixtures tested to be included in the tables and the discussion which follows.

Table 2.--Foliage injury resulting from ordinary spray concentrations applied at Milford and Orange, Conn., in 1938

Mixture No.	Pounds of insecticide per 100 gallons (833 pounds) of water	Proportion of insecticide remaining after rains totaling--[1] 0.18 inch	Proportion of insecticide remaining after rains totaling--[1] 2.2 inches	Soluble As_2O_5 per pound of arsenical	Degree of injury to wild black cherry
		Percent	Percent	Milligrams	
1	Calcium arsenate (A),[2] 3.	14	1	1,385	Severe injury in 7 days. Most of leaves shed in 30 days.
2	Calcium arsenate (B),[3] 3.	10	1	1,250	Severe injury as in case of mixture No. 1. Most of leaves shed in 30 days.
3	Lead arsenate, 3.	60	13	650	Light injury in 7 days. Medium to heavy injury in 30 days, with no shedding of leaves.
4	Lead arsenate, 3; fish oil, 0.25	45	20	675	Very little injury in 7 days. Medium injury in 30 days, similar to mixture No. 3.
5	Lead arsenate, 3; spreader (a),[4] 1.0	5	1	1,400	Severe injury in 7 days. Most of leaves shed in 30 days. Adherence poor.
6	Calcium arsenate (A), 3; spreader (a),[4] 1.0	2	1	1,600	Injury severest of all mixtures. Leaves began dropping in 6 days. Poor adherence.
7	Bordeaux mixture (copper sulfate, 8; hydrated lime, 8)	75	45	--	Very light injury in 7 days. Light to medium injury in 30 days, with no shedding.
8	Copper sulfate, 2; hydrated lime, 3; calcium arsenate (B), 3.	65	30	25	Very slight injury to lower leaves in 8 days. Medium injury in 30 days. Similar to mixture No. 1.
9	Lead arsenate, 3; $FeSO_4.7H_2O$ (copperas), 6.4; hydrated lime, 1.6	90	50	5	Very light injury in 30 days. Some light spotting on a few leaves.

[1]Adherence determined by chemical analysis of leaf samples having a total leaf surface of at least 1,000 sq. in.
[2](A) Ordinary calcium arsenate.
[3](B) A so-called "safe" calcium arsenate.
[4]Spreader (a) is alkylphenylbenzenesulfonic acid (aresket).

When bordeaux mixture was added to arsenicals, the injury was reduced. The copperas-lime mixture (mixture 9, table 2, and mixture 21, table 3) greatly reduced the injury caused by lead arsenate. The addition of spreaders in most cases tended to reduce the deposit and adherence and increase the injury, particularly in the case of ordinary spray concentrations.

When lead arsenate (mixture 3, table 2) was prepared in a standard spray concentration, 650 milligrams of As_2O_5 were soluble per pound of lead arsenate in the mixture, while only 55 milligrams were soluble in the concentrate (mixture 1, table 3). When calcium arsenate (mixture 1, table 2) was applied in a standard spray concentration, 1,385 milligrams of As_2O_5 were soluble per pound of calcium arsenate, while only 4 milligrams were soluble in the concentrate (mixture 2, table 3). When calcium arsenate was applied in a hydrated lime-soybean flour-casein glue mixture (mixture 19, table 3) there was practically no solubility or injury. The concentrated spray mixtures applied caused much less injury to wild black cherry than the ordinary spray concentrations, as found by comparing the items in the last column of table 2 with those of table 3.

By using concentrated sprays (table 3) it was possible (1) to apply mixtures which contained less water-soluble insecticide (column 5, table 3) because of the small amount of water and wetting agent present, and (2) to coat effectively the particles or residue with casein or drying and semidrying oils, thus protecting both insecticide and plant. Therefore, the use of concentrated sprays makes it possible to avoid or greatly reduce foliage injury caused by many of the more common insecticides, such as the arsenicals, cryolite (mixture 22), or barium fluosilicate (mixture 23). Mixtures 1 and 2 contained no adhesives, spreaders, or "safeners." They caused more injury and had poorer adherence than mixtures 11, 14, 19, 21, 22, and 23, which contained adhesives, spreaders, or "safeners."

Nondrying mineral oils were slightly more toxic to plants than nondrying plant oils. Drying oils, as fish oil, linseed oil, and tung oil, and semidrying plant oils, as cottonseed oil, soybean oil, and corn oil, were relatively non-toxic to plants, even when heavy applications of the undiluted oil were made.

Dust deposits caused less injury than ordinary spray deposits, since (1) the quantity of initial dust deposit per given leaf area was less than the initial spray deposit following the application of a given quantity of insecticide and (2) the loss of dust deposit caused by wind and rain was far greater than the loss of spray deposit. Therefore the plant was exposed to less of the phytotoxic agent over any given period of time when the insecticide was applied as a dust.

Deposit and Adherence Resulting from the Use of Dust, Ordinary Spray, and Concentrated Spray

Twenty-five concentrated spray mixtures, most of which gave uniformly high adherence, are shown in table 3. Figure 8 shows additional data on the deposit and adherence resulting when certain insecticides were applied as

Table 3.--Some concentrated spray mixtures applied at Milford and Orange, Conn., in July and August 1938, with special reference to foliage injury and adherence

Mixture No.	Proportion (by weight) of materials in mixture[1]	Proportion of insecticide remaining after-- 1.4 to 2 inches of rain	Proportion of insecticide remaining after-- 16 to 18 inches of rain	Soluble As_2O_5 per pound of arsenical	Remarks[2]
		Percent	Percent	Milligrams	
1	L.A., 1; water, 2	13	5	55	Medium to severe injury, and light shedding of leaves of wild black cherry.
2	C.A., 1; water, 2	2	1	4	Complete defoliation of wild black cherry.
3	L.A., 1; water, 1.2; L.O., 0.16; P.O., 0.4; S.L.S., 0.03	87	42	76	Very slight injury to wild black cherry.
4	C.A., 1; water, 2; C.O., 0.25	88	25	4	Severe injury to wild black cherry. No injury to other species.
5	L.A., 1; water, 1.5; F.O., 0.2; R.O., 0.05; T., 0.025	95	44		Little to no injury to wild black cherry.
6	L.A., 1; water, 1.5; P.O., 0.1; L.O., 0.1; R.O., 0.05; T., 0.025	90	38		Light injury to wild black cherry. Spread well.
7	L.A., 1; water, 1.5; C.O., 0.2; R.O., 0.05; T, 0.025	93	40		Very little injury to wild black cherry.
8	L.A., 1; water, 1.5; C.O., 0.15; R.O., 0.04; T, 0.02	83	27		Light injury.
9	L.A., 1; water, 1.5; C.O., 0.1; R.O., 0.04; T, 0.02	84	24		Light injury to wild black cherry.
10	L.A., 1; water, 1.5; S.B.O., 0.2; R.O., 0.05; T., 0.025	85	43		Little to no injury to wild black cherry.
11	L.A., 1; water, 1.5; C.S.O., 0.2; R.O., 0.06; T., 0.025	92	44		No injury.
12	L.A., 1; water, 1.5; casein glue, 0.1	85	22		Slight injury to wild black cherry.

[1]L.A., Lead arsenate. C.A., calcium arsenate. L.O., linseed oil. P.O., paraffin oil. S.L.S., sodium lauryl sulfate. C.O., corn oil. F.O., fish oil. R.O., red oil or oleic acid ($C_{17}H_{33}COOH$). T., triethanolamine ($N(C_2H_4OH)_3$). S.B.O., soybean oil. C.S.O., cottonseed oil. Spreader (A), alkylphenylbenzenesulfonic acid (aresket).

[2]Injury record covers the first 6 weeks of exposure.

Table 3.--Continued.

13	L.A., 1; water, 1.5; C.O., 0.2; casein glue, 0.05; T., 0.0075	88	45		Practically no injury.
14	L.A., 1; water, 1.5; C.O., 0.2; sulfonated castor oil, 0.11	92	36		Practically no injury.
15	L.A., 1; water, 1.5; L.O., 0.2; sulfonated castor oil, 0.11	93	60	60	No injury. The castor oil reduced the drying of finely atomized droplets.
16	L.A., 1; water, 1.75; soybean flour, 0.1; C.O., 0.2	80	26		Slight injury to wild black cherry. Very noticeable spreading.
17	L.A., 1; water, 2; soybean flour, 0.1; C.O., 0.2; casein glue, 0.05	82	20		Very little injury.
18	C.A., 1; water, 2.5; soybean flour, 0.1; C.O., 0.2; casein glue, 0.05	90	--		Severe injury to wild black cherry leaves. Not so severe as for mixture No. 2.
19	C.A., 1; hydrated lime, 4; soybean flour, 1; casein glue, 0.5; C.O., 2.0; water, 27	76	18	2	No injury to wild black cherry.
20	L.A., 1; water, 1.5; C.O., 0.2; spreader (A), 0.4	92	40		Very little injury to wild black cherry. Noticeable spreading.
21	L.A., 1; water, 1.9; $FeSO_4.7H_2O$ (copperas), 0.3; hydrated lime, 0.076 (prepared as for bordeaux mixture)	84	23	1	Practically no injury. Good atomization. Good adherence.
22	Synthetic cryolite, 1; water, 1.25; C.O., 0.2; T., 0.02	60[3]	--		Little to no injury.
23	Barium fluosilicate, 1; water, 0.8; F.O., 0.2; spreader (A), 0.02	91[3]	40[3]		No injury.
24	Sulfur, 1; water, 1.25; soybean flour, 0.05; C.O., 0.05; P.O., 0.05; casein glue, 0.04; T., 0.02	86[3]	27[3]		No injury.
25	Derris, 1; water, 6; C.O., 0.3; spreader (A), 0.04	78[3]	30[3]		

[3]Adherence record is based on a visual estimate. Adherence of each of the other mixtures was determined by chemical analysis of leaf samples having a total leaf surface of at least 1,000 square inches.

dust, as ordinary spray, and as concentrated spray to relatively large areas. About 1,350 acres of woodland were treated in the experiments represented by figure 8. In this figure the plots represented by columns 3 and 4 were sprayed from the ground, while those represented by columns 1, 2, and 5 were treated from the air. The growth ranged from 35 to 90 feet in height. The first 4 columns represent plots exposed to between 0.86 and 1.14 inches of rain, or an average of 1 inch. The concentrated spray (last column) was exposed to an average of 5.7 inches of rain.

When ordinary spray concentrations of lead arsenate were applied there was considerable variation in the deposit on different types of foliage, whereas the quantity and distribution of concentrated spray deposit were equal on all surfaces. The ordinary spray deposit on foliage of trembling aspen and gray birch, and on the growing leaves and needles and waxy buds of pine was only 36 to 73 percent of that on mature oak and maple foliage.

Forty-two percent of the standard spray mixture fell to the ground (columns 3 and 4, figure 8) when sprayed on oak trees 40 feet in height,[7] and when sprayed on trees 70 to 90 feet in height the loss was 65 percent. Part of the ground deposit of ordinary spray was due to drippage and "run-off." The first inch of rain removed 68 percent of the initial leaf deposit when no adhesive was added and 35 percent when fish oil was added.

When lead arsenate was applied in a concentrated spray mixture only 10 to 18 percent of the insecticide fell to the ground at the time of application and only 12 percent of the leaf deposit was removed by 5.7 inches of rain. In the region covered by the investigations there is an average of 3.4 inches of rain per month during the summer, with 10 to 12 days per month on which rain falls, averaging 0.3 to 0.34 inch every third day. The amount and frequency of rainfall are important factors in influencing adherence of dusts and standard spray mixtures.

When applied in standard spray concentrations, lead arsenate adhered better than all other common insecticides except lime-sulfur and bordeaux mixture. Lead arsenate dust adhered much better than all other uncoated insecticidal dusts.

Figure 8 shows great differences in the final deposits of dusts, ordinary sprays, and concentrated sprays. The unshaded portion of column 1 represents the percentage of total dust applied which <u>did not settle on the foliage</u> plus the percentage which was <u>removed by wind</u> averaging 5 miles per hour. The unshaded portion of column 2 represents only that portion of the dust applied which, in the absence of air movement, did not settle on the

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[7]The method used in determining the quantity and percentage of total insecticide applied which fell to the ground, or was deposited on the foliage, is fully described in the following paper: Potts, S. F. A method for determining the quantity of foliage per acre of woodland. Jour. Forestry 37 (12): 922-923. 1939.

foliage. The two kinds of insecticidal loss included in the unshaded portion of column 1 are much greater than the loss caused by rain. A very striking contrast is seen by comparing dust (columns 1 and 2) with concentrated spray (column 5). The initial concentrated spray deposit was 2.27 and 6.8 times as great as the dust deposits. After 10 days' weathering the concentrated spray deposit averaged 7 to 17.5 times as great as the dust deposits. When a given quantity of lead arsenate was applied under favorable dusting conditions from the ground as a concentrated spray and as a dust, the deposit per unit of area after an average of 10 days' exposure was 5 times as great on areas treated with concentrated spray as on those treated with dust. After an average of 10 days' exposure, an average of 15 percent of the dust applied was on the foliage as compared with 75 percent in the case of concentrated spray. Loss of the dust deposit was greatest at the tree tops.

Close examination of the action of dust particles in motion around the leaves showed that most particles passed over the leaves like smoke without adhering. This was partly due to the difference between air temperature and leaf temperature, which causes air currents at the leaf surface. This condition was less pronounced on conifers than on broad-leaved trees. These facts demonstrate the marked superiority of concentrated sprays over dusts, whether applied from the ground or from the air.

Advantages and Disadvantages of Concentrated Spray Applications as Compared with Dusting and Standard Spraying Methods

In some cases aerial dusting has an advantage over spraying with concentrates in that more insecticide can be carried, owing to the absence of water. This is not always true, however. For example, several times as much of the toxic principle can be carried in a given weight or volume of liquid concentrates, in the form of derris extract, pyrethrum extract, nicotine solution, etc., as can be carried in a dust. For ground dusting from 4 to 9 parts of carrier are usually used per part of insecticide. Therefore, in order to apply 20 pounds of insecticide per acre it is necessary to use from 100 to 200 pounds of dust. In general, during the period of actual operation, areas may be covered more rapidly by dusting than by spraying with concentrates, but owing to unfavorable wind conditions the number of hours available for dusting is only about one-fourth as great as for spraying with concentrates.

As compared with dusting, spraying with concentrates gives a heavier initial deposit (without loss of initial deposit by wind), better adherence, and less drift, requires less tank or hopper space, can be accomplished over more rugged terrain, and is more effective.

Many powdered insecticides which cannot be applied as contact dusts can be applied as contact sprays in the form of concentrated spray mixtures. Furthermore, liquid insecticides, such as bordeaux mixture, lime-sulfur, undiluted oils, oil emulsions and miscible oils, derris extract, nicotine solution, and nicotine tannate, may be applied as concentrates, whereas they cannot be applied effectively or at all as dusts. Sulfur and such organic dusts as derris and pyrethrum cause serious fire hazards in aerial dusting work, but this hazard is removed when these materials are applied as concentrated sprays.

The standard spraying method has one advantage over both dusting and spraying with concentrates in that often the tendency of excess spray to run off the foliage serves as an automatic check against excessive deposits. On the other hand, experience gained thus far indicates that, as compared with the standard spray method, the concentrated spray method covers areas more quickly and requires less insecticide, labor, equipment, and expense. It gives a heavier deposit, better adherence, and less foliage injury. Instances will doubtless occur, however, where standard spraying and dusting methods will be preferable to the concentrated spray method, and a final appraisal of the different methods is withheld until the entomological, chemical, and mechanical phases of the latter are fully developed.

SUMMARY

Although a new kind of equipment is needed for applying concentrated sprays, certain types of ready-made devices, such as hand atomizers, paint spray outfits, and conventional sprayers equipped with special nozzles, can be used at present or modified and assembled for use. Experiments which suggest the kind of apparatus and degree of atomization desired have been conducted. Tests of equipment indicate that, as compared with the standard spray method, the concentrated spray method covers areas more quickly and requires less equipment, labor, insecticide, and expense.

A detailed study of dusts, ordinary sprays, concentrated spray mixtures, and residues was made in the laboratory and field, and methods of preparing concentrated spray mixtures of many of the more important insecticides and fungicides were developed.

The addition of weak bordeaux mixture to either concentrated spray or ordinary spray concentrations containing lead arsenate or calcium arsenate considerably reduced the injury to susceptible plants. A copperas-lime mixture (4 parts of $FeSO_4.7H_2O$ to 1 part of hydrated lime) practically eliminated foliage injury caused by lead arsenate. Concentrated spray mixtures greatly reduced injury, since they contained very little or no wetting agent and water, and the residue was coated with certain oils or other adhesives. This protected both the residue and the plant, so that calcium arsenate, cryolite, certain oils, and other materials were less phytotoxic.

When lead arsenate was applied in standard spray concentrations to woodland trees 40 to 90 feet tall, from 42 to 65 percent of the insecticide fell to the ground. The first inch of rain removed 68 percent of the leaf deposit if no adhesive was used, or 35 percent if fish oil was added. When applied in ordinary spray mixtures, lead arsenate adhered better than all other common insecticides except lime-sulfur and bordeaux mixture.

Concentrated spray mixtures can be made to adhere better than ordinary spray concentrations. A heavier initial deposit of insecticide was obtained per unit of area, owing to the absence of drippage and run-off. The use of drying oils or semidrying plant oils in concentrated sprays greatly increased the adherence of the spray residues, so that a considerable portion of the initial deposit was present on the foliage after 3 months of weathering, including 16 to 18 inches of rain.

Concentrated spray mixtures were superior to dusts. They gave a much heavier deposit, with better adherence, less drift, and no loss by wind, required less insecticide, and could be applied during periods of the day when there was too much wind for dusting. When lead arsenate dust was applied from the air, from 4 to 10 percent of the insecticide applied was present on the foliage after an average of 10 days of weathering. When applied from the ground under favorable dusting conditions, an average of 15 percent of the insecticide applied was on the foliage after 10 days of weathering, as compared with approximately 75 percent in the case of concentrated spray. Lead arsenate dust adhered better than all other common insecticidal dusts. Drift, air currents around the leaves, wind after treatment, and rain caused low dust deposits.

When various organic insecticides, such as derris, derris extract, and nicotine, were applied in concentrated form it was possible to ccat the insecticidal agent sufficiently to reduce greatly the deterioration caused by light, air, and moisture.

Excellent coverage and adherence on wet foliage resulted from concentrated sprays applied either before, during, or following rain.

Tests indicate that many insecticides may be stored safely as concentrated spray mixtures for long periods of time. This should permit the marketing and use of ready-made mixtures, and thus avoid the difficulties often encountered by growers in weighing, measuring, and mixing insecticidal materials.

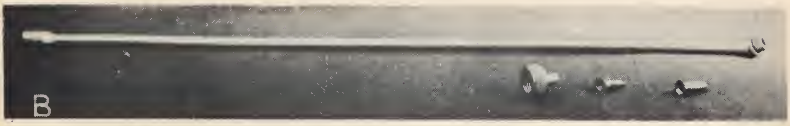

Figure 1.--A, Nozzle for use in applying concentrated spray with ordinary ground equipment. It consists of a brass shell with a hole 1/50 to 1/16 inch, or 0.5 to 1.6 millimeters, in the smaller end, a hollow screw with a hole near the center, and a large brass cap for holding the shell and screw in place.
B, Large brass cap containing the shell and screw which can be screwed to ordinary extension rods. The short rod shown has the nozzle coupling attached at an angle of 45° for treating leading shoots of pine trees with a solid cone type of spray.

Figure 2.—Rhododendron leaves sprayed with concentrated spray mixtures applied by a knapsack sprayer. The spray deposit was exposed to 2 years of weathering, and during this time 80 inches of rain fell.

Figure 3.—Leaves collected, after 4.8 inches of rain, from trees sprayed with a concentrated spray mixture applied by a paint spray gun outfit.

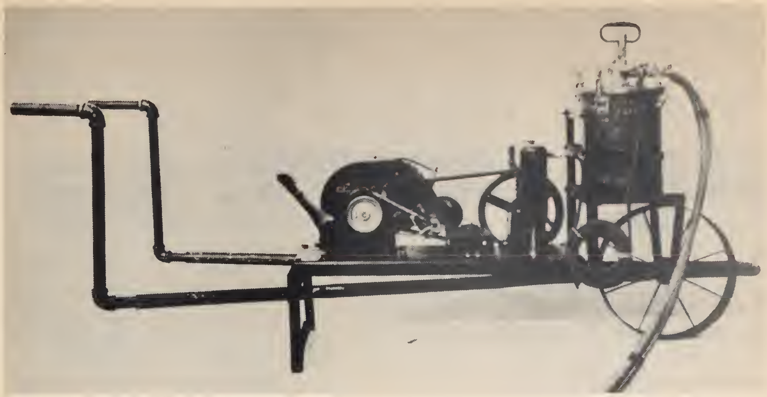

Figure 4.—Paint spray outfit used for applying concentrates.

Figure 5.—A paint spray gun nozzle used with the apparatus of figure 4.

Figure 6.—Low-growing trees being treated with concentrates, applied by a paint spray gun outfit.

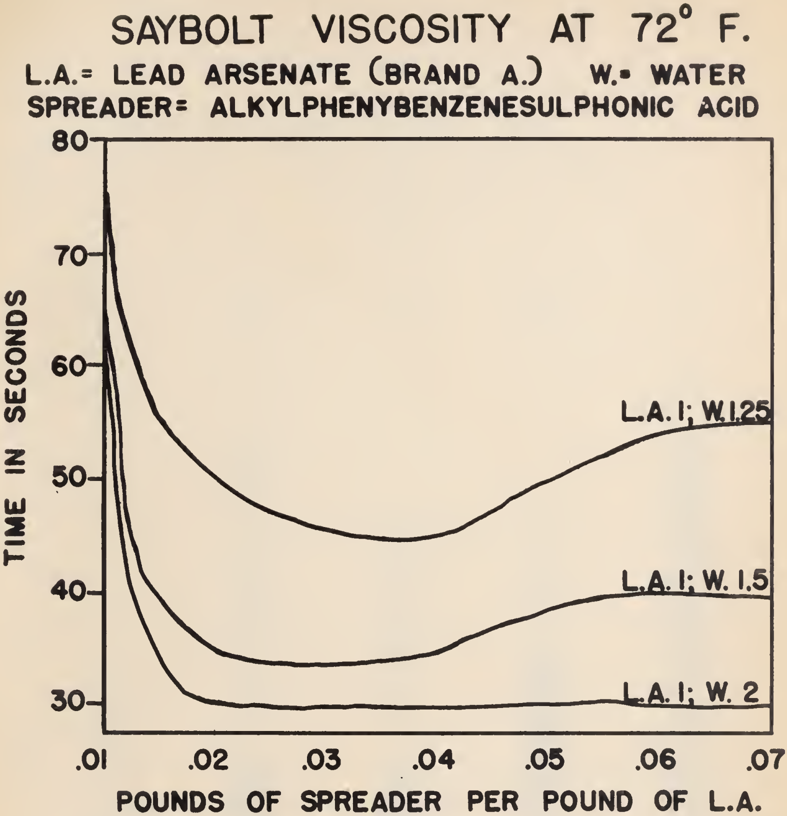

Figure 7.--Viscosity chart, showing the rate of flow of lead arsenate concentrates through an aperture of 1.76 millimeters (0.07 inch) at the usual field spraying temperature.

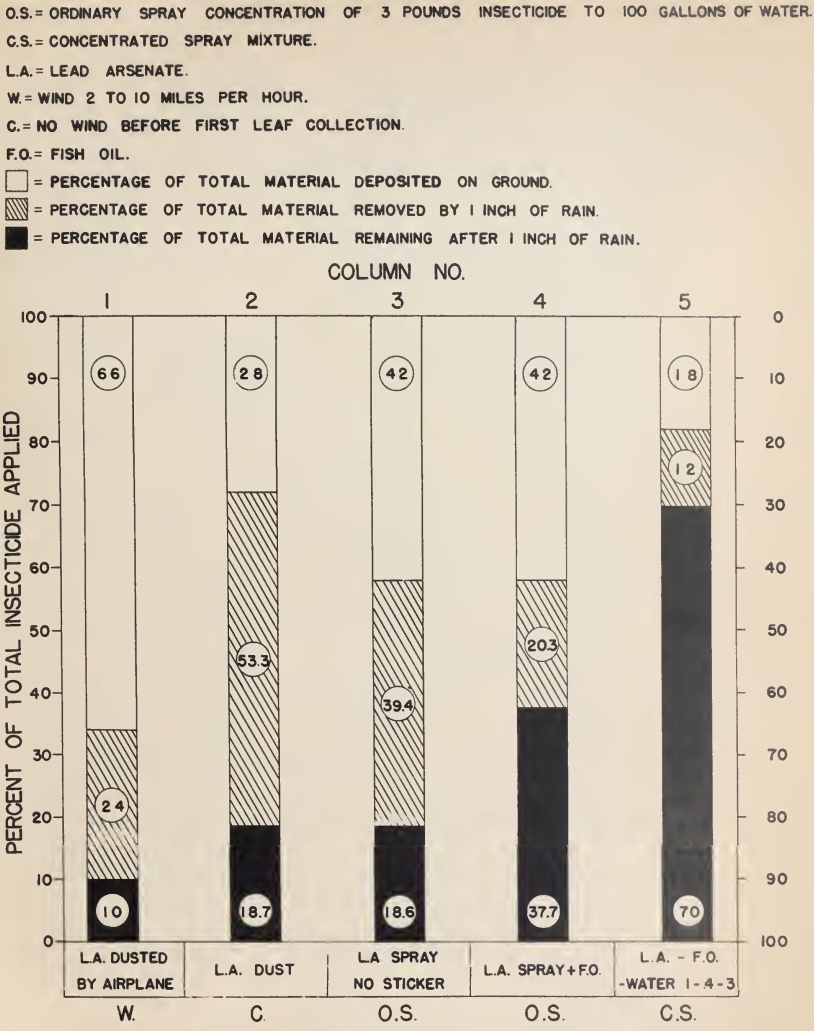

Figure 8.--Comparison of the influence of rain, wind, and other physical factors on the loss of insecticide when applied as a dust, an ordinary spray concentration, and a concentrated spray mixture.